Trapping of a microsphere pendulum resonator in an optical potential

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1. Introduction

Optical microcavities confine light to small volumes by resonant recirculation. In recent years, microcavities have become a very active area of research, with applications in nonlinear optics, sensing, cavity quantum electrodynamics and optomechanics.

Tapered optical fibre has been shown to be the most efficient tool to couple light into microspherical cavities, resulting in whispering gallery mode generation within the cavities.

The highly concentrated light in optical microcavities is able to generate a significant force on the scale of nano-Newtons. Previous theoretical work [1] has predicted attractive and repulsive forces arising from interacting modes of two evanescently coupled microspheres. We propose a method [2] to spatially confine the movements of a micropendulum via the optical forces produced by two simultaneously excited optical modes of a photonic molecule comprising two microspherical cavities. This result presents opportunities for very precise all-optical self-alignment of microsystems.

2. Whispering Gallery Modes

Light travelling inside a cavity, of radius *r*, strikes the surface at an angle of incidence greater than the critical angle, then undergoes total internal reflection.
If the cavity is of good quality (e.g. smooth surface, low eccentricity), light can undergo multiple reflections, which leads to long photon storage lifetimes and high Q-factors.

The electric field of modes of the microsphere are given by:

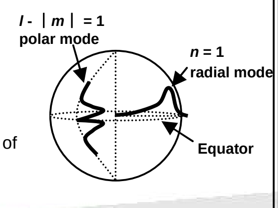
$$E(r,\theta,\phi)\propto j_n(kr)Y_l^m(\theta,\phi)$$

j_n, Y_l^m are spherical Bessel and Harmonic functions.

n = number of maxima in radial extension;

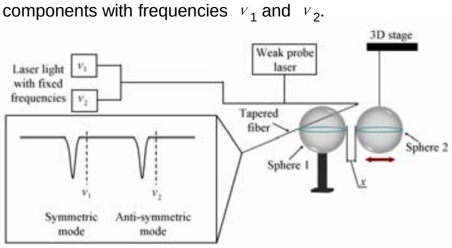
l = number of maxima in angular variation of field around sphere equator;

$m = -l, -l+1, \ldots, 0, \ldots, l+1, l$



3. Proposed Experimental Setup

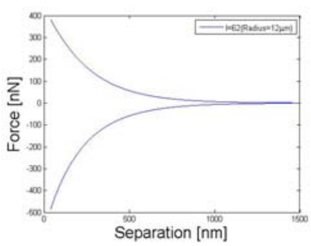
A schematic of the proposed experiment is shown here. A photonic molecule, consisting of two microspheres, is optically pumped by two-frequency laser light through a tapered optical fibre. Sphere 1 is fixed and unable to move, while Sphere 2 is suspended by a thin fibre stem and acts as a pendulum. The length of the stem can be chosen in order to ensure that the pendulum has the desired spring constant. The pumping laser field consists of two monochromatic field components with frequencies ν_1 and ν_2.



Inset shows the transmission of a weak probe signal as a function of frequency for a given separation, *x*, between the microspheres.

4. Optical Resonant Force

Modal splitting appears when two microspheres get close enough (~1 μm) to each other due to the interaction between them. The splitting causes symmetric and anti-symmetric modes to be established in the spheres. This is considered to be the optical analogue to bonding and anti-bonding modes in an atomic molecule.



When the symmetric mode of the photonic molecule is excited resonantly, there is an attractive force generated which tends to pull the spheres together; exciting the anti-symmetric resonance results in a repulsive force which pushes the spheres apart.

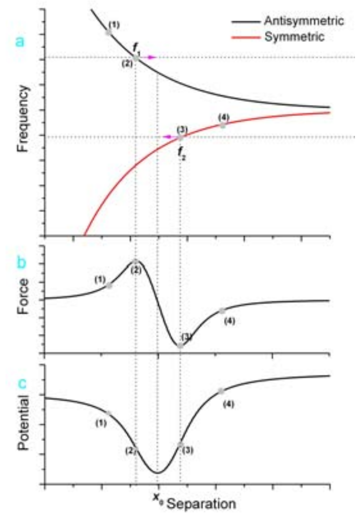
$$F = -\frac{1}{\omega_0}U_0\frac{\partial\omega}{\partial x}$$

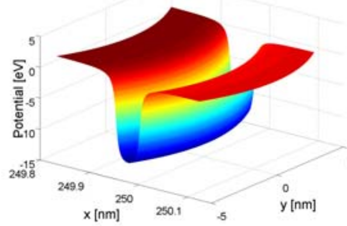
5. Optical Potential

When the system is excited with two fixed laser lines, which are blue-detuned from the symmetric and anti-symmetric resonant positions, the attractive and repulsive forces would generate a deep potential well to trap the movable sphere spatially.

When the system is off resonance (points 1 & 4 in Fig. a-c), the forces are negligible. As the separation between the spheres increases, the symmetric mode will be excited resonantly (point 2) by the first laser line at the frequency of f_1 and the repulsive force will push the spheres apart.

When the movable sphere goes so far away that the anti-symmetric mode shifts to higher frequency of f_2 (point 3) and the relevant attractive force would draw the spheres together. At the equilibrium position x_0, the net force is zero. Hence, the net force between the spheres is shown in Fig. b and the corresponding potential well is presented in Fig. c.





For a pair of spheres with radii of 12.5 μm, Q of 10^8, and an input power of 1 mW, the potential well could be 13 eV deep and 30 pm wide. Detuning frequencies f_1 and f_2 are three laser linewidths away from the resonant frequencies of the equilibrium position.

6. Conclusion

In conclusion, we have proposed a method to trap and corral an optomechanical system consisting of two microspheres. We have shown that the optical radial potential could be 13 eV deep and 30 pm wide. We also note that the depth of the optomechanical potential well is far greater than the thermal fluctuations k_BT (~25 meV at room temperature).

References

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Acknowledgements

This work was supported in part by Science Foundation Ireland under Grant Nos. 06/W.1/I866 and 07/RFP/PHYF518.

Yuqiang Wu acknowledges support from IRCSET through the Embark Initiative.